



Science Team Meeting, January 7-9, 2014, Washington DC

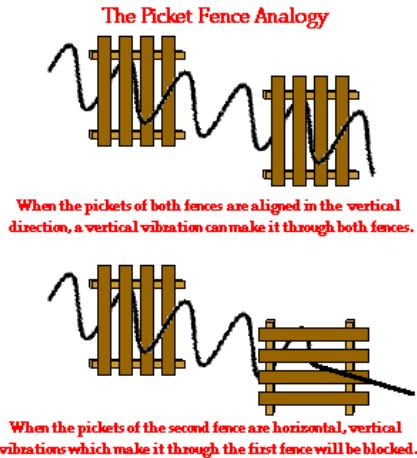
## **Modeling Polarized Solar Radiation for CLARREO Inter-calibration Applications: Validation with PARASOL Data**

**Wenbo Sun, Constantine Lukashin, and Daniel Goldin**

- **Introduction**
- **Status of the adding-doubling radiative transfer model (ADRTM)**
- **Comparison of ADRTM results with PARASOL data**
- **Summary**

## Background

Many satellite sensors have polarization dependence



Any arbitrarily polarized incoherent radiation can be represented by the linear sum of an unpolarized part and a 100% polarized part as

$$I_{pol} = \sqrt{Q^2 + U^2 + V^2} = DOP \cdot I$$

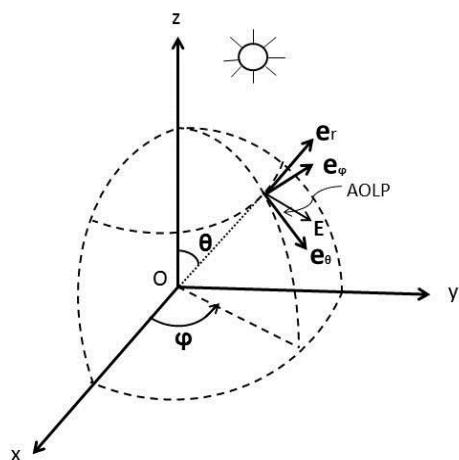
$$I_{unpol} = I - \sqrt{Q^2 + U^2 + V^2} = (1 - DOP) \cdot I$$

$$DOP = \frac{\sqrt{Q^2 + U^2 + V^2}}{I} = I_{pol} / I$$

$$\tan(2AOLP) = \frac{U}{Q}$$

Correction of polarization error is done as

$$I = \frac{C_m / G_0}{1 + \left[ \frac{G_p(AOLP) - G_0}{G_0} \right] \cdot DOP}$$



## Introduction

1. Satellite imagers all have some polarization dependence. To enable the inter-calibration of CLARREO and imagers, PDMs need to be built to correct the imager data.
2. PARASOL data can be used for empirical PDMs. But PDMs based on PARASOL is insufficient to cover all solar/viewing angles and solar spectra, and not well related to detailed atmospheric conditions.
3. Modeling is necessary for PDMs over whole solar spectra and all incidence and viewing geometries and is critical for stratification of the PDMs and polarization sensitivity studies.

# Status of the adding-doubling radiative transfer model (ADRTM)

## 1. ADRTM:

This can calculate full Stokes parameters (I, Q, U, V).

## 2. Atmospheric profiles:

Any atmosphere profile.

## 3. Spectral gas absorption:

Line-by-Line and  $k$ -distribution plus ozone cross-section table.

## 4. Molecular scattering:

Rayleigh with depolarization factor.

## 5. Particulate absorption and scattering:

Mie for water clouds (Gamma size distribution);

PML/UPML FDTD for fine-mode aerosols;

CPML PSTD code is developed for coarse-mode aerosols;

FDTD, PSTD, and GOM for ice clouds are being considered...

## 6. Surface reflection model:

Lambert surface for land now.

More practical model for land is being considered with PARASOL data...

Cox & Munk with/without Gram-Charlier expansion plus foam for ocean;

Wave shadowing effect is integrated in the ocean surface model;

Lambert model for water-leaving radiance from ocean water volume.

More practical model for water-leaving radiance is being considered...

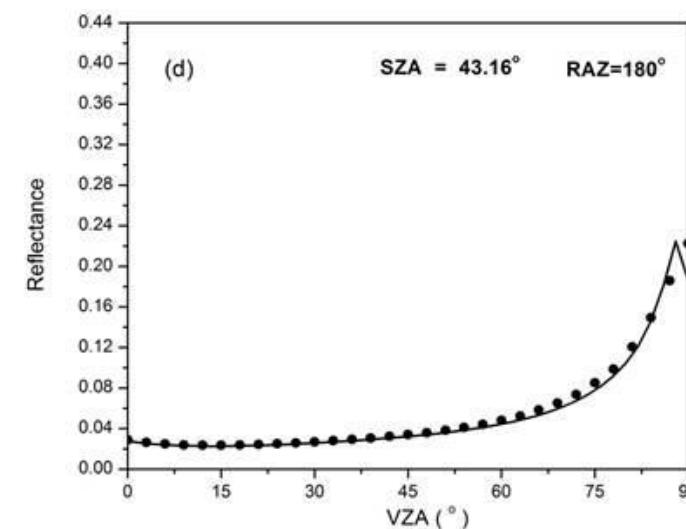
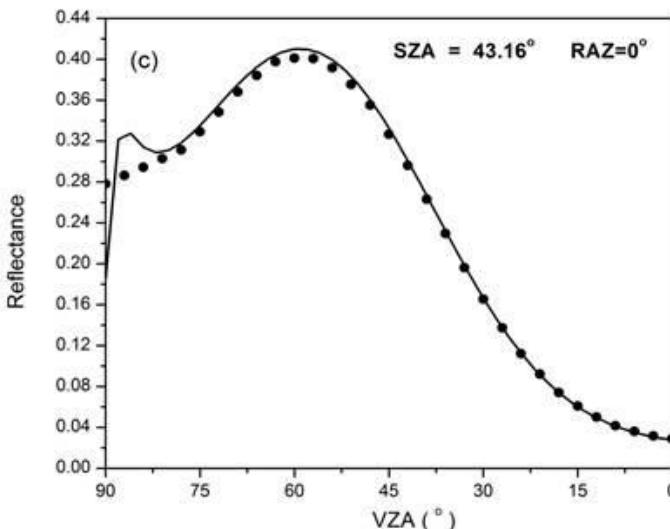
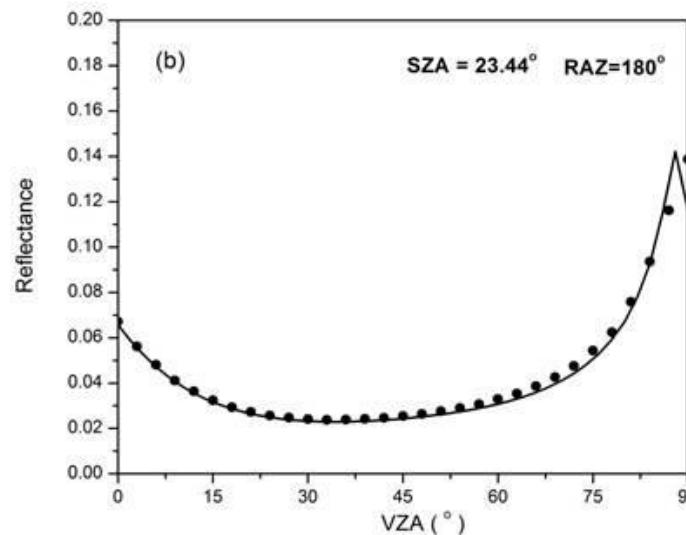
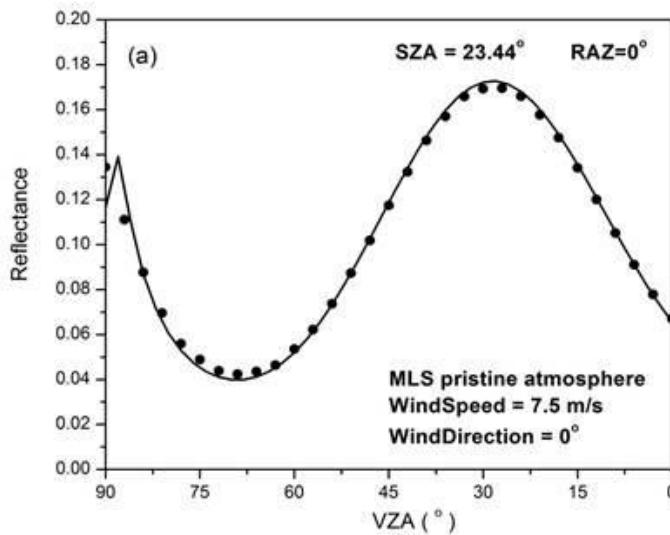
## 7. Output:

polarization parameters are mapped to uniform angular grids.

## 8. Goal:

PDMs of whole CLARREO solar spectra for all major scene types ...

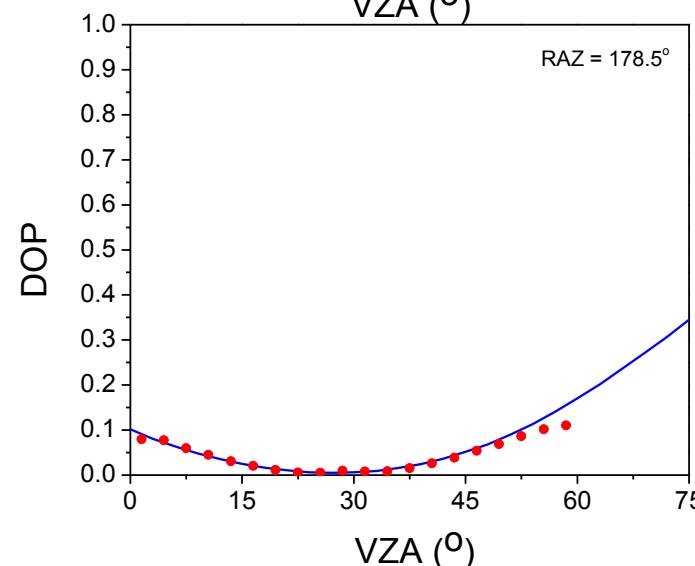
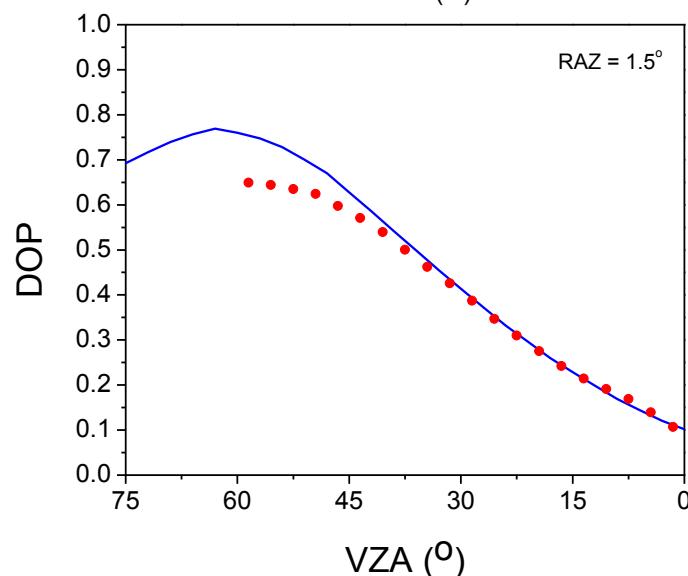
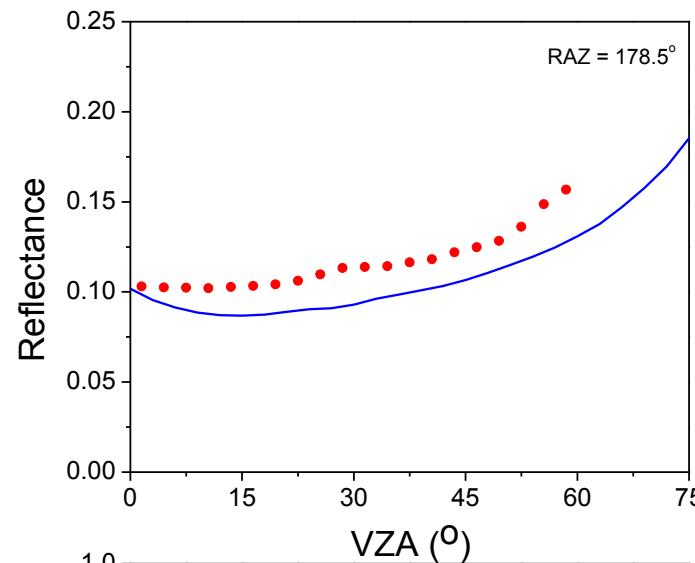
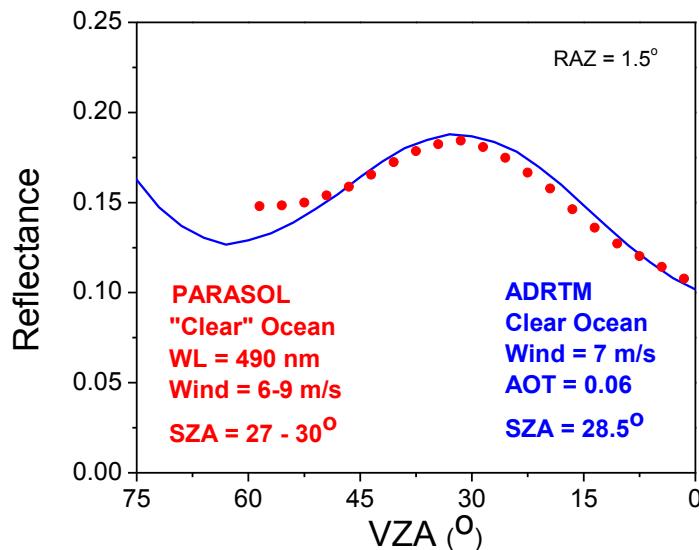
# Comparison of reflectance at 670 nm from DISORT (solid curves) and ADRTM (black dots)



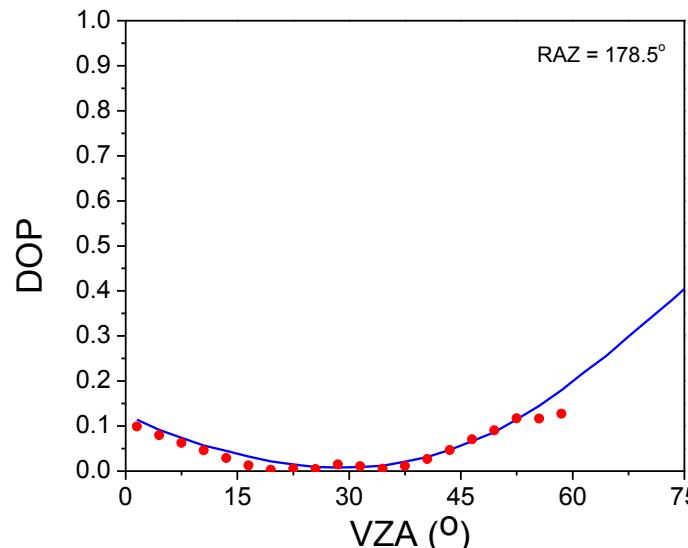
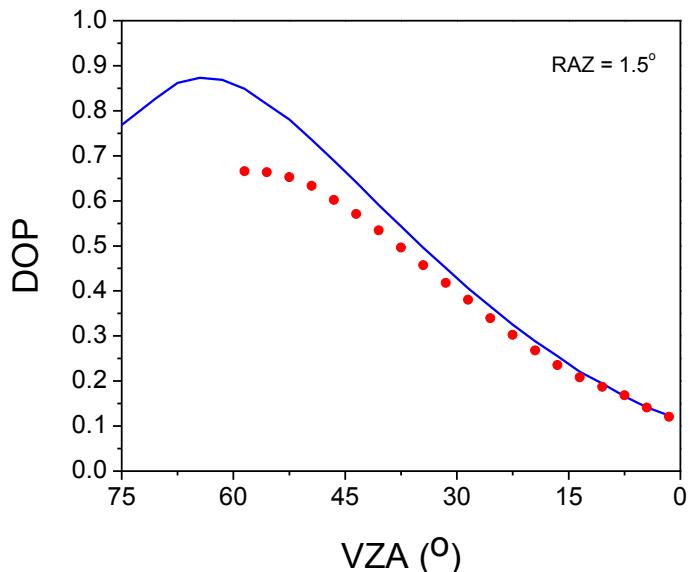
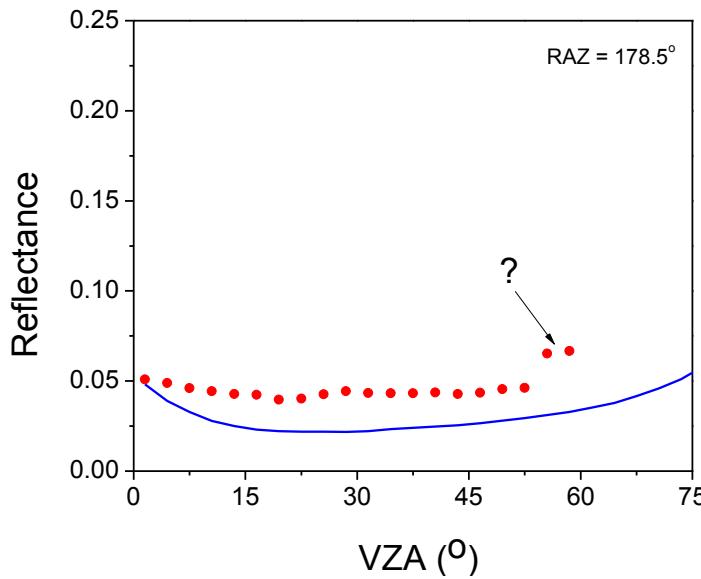
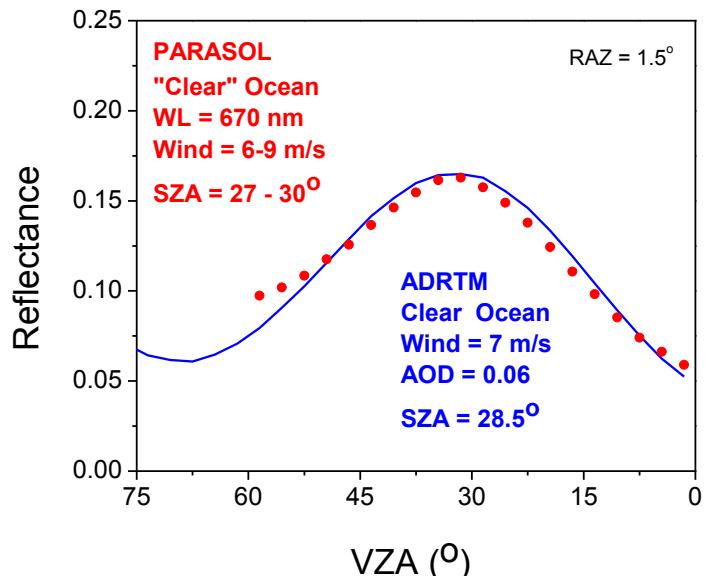
# Comparison of ADRTM results with PARASOL data

24 days PARASOL data in the 12 months of 2006 are used

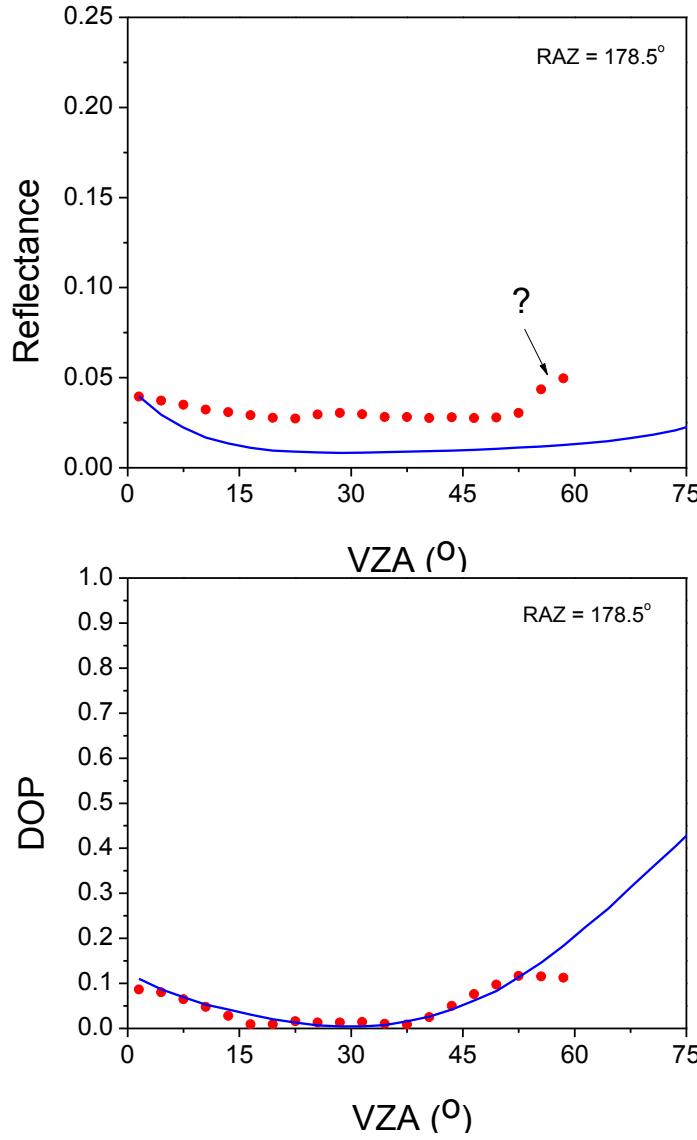
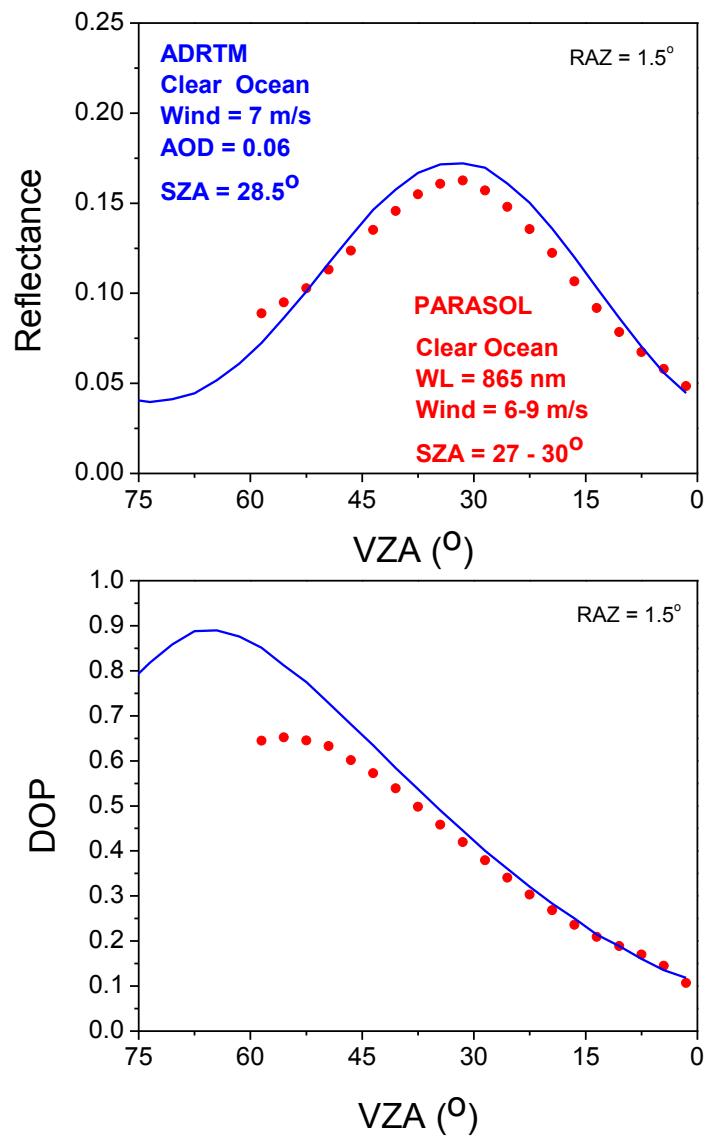
WL = 490 nm



## WL = 670 nm

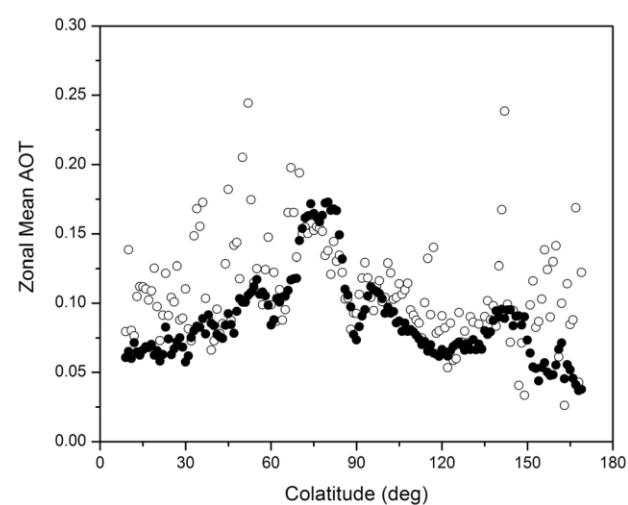
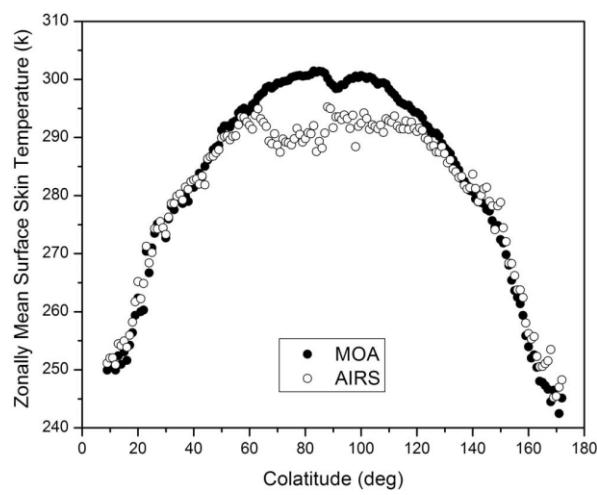
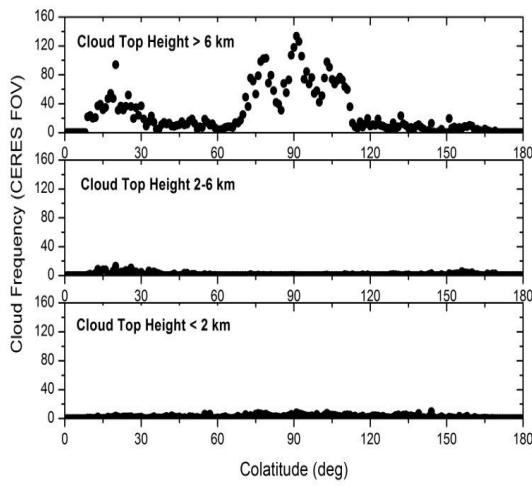
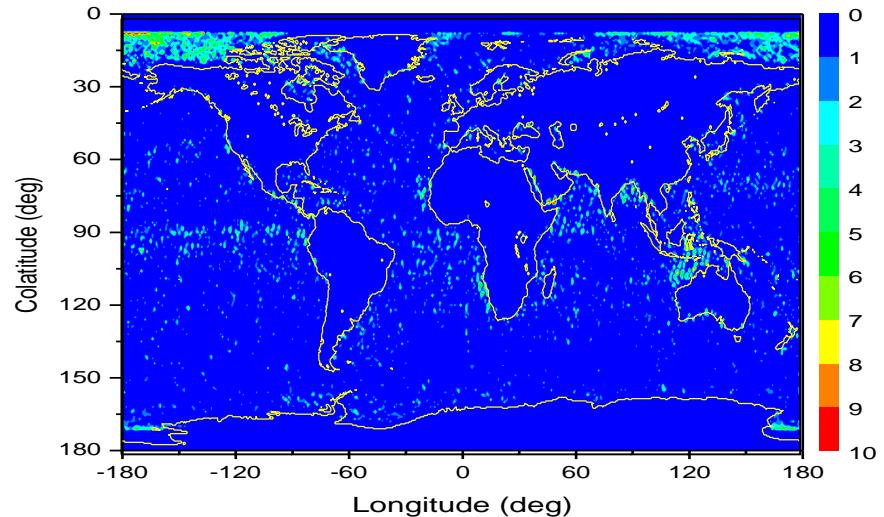
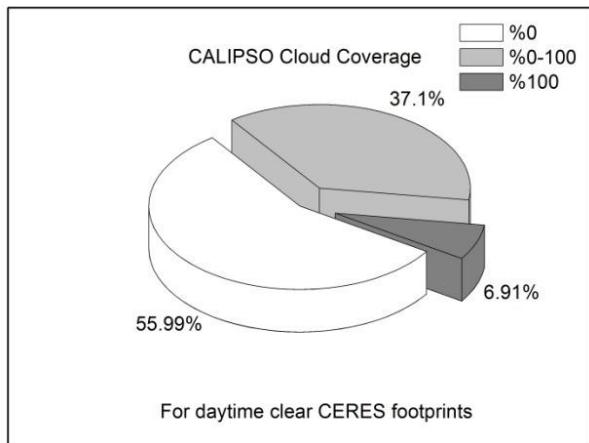


## WL = 865 nm



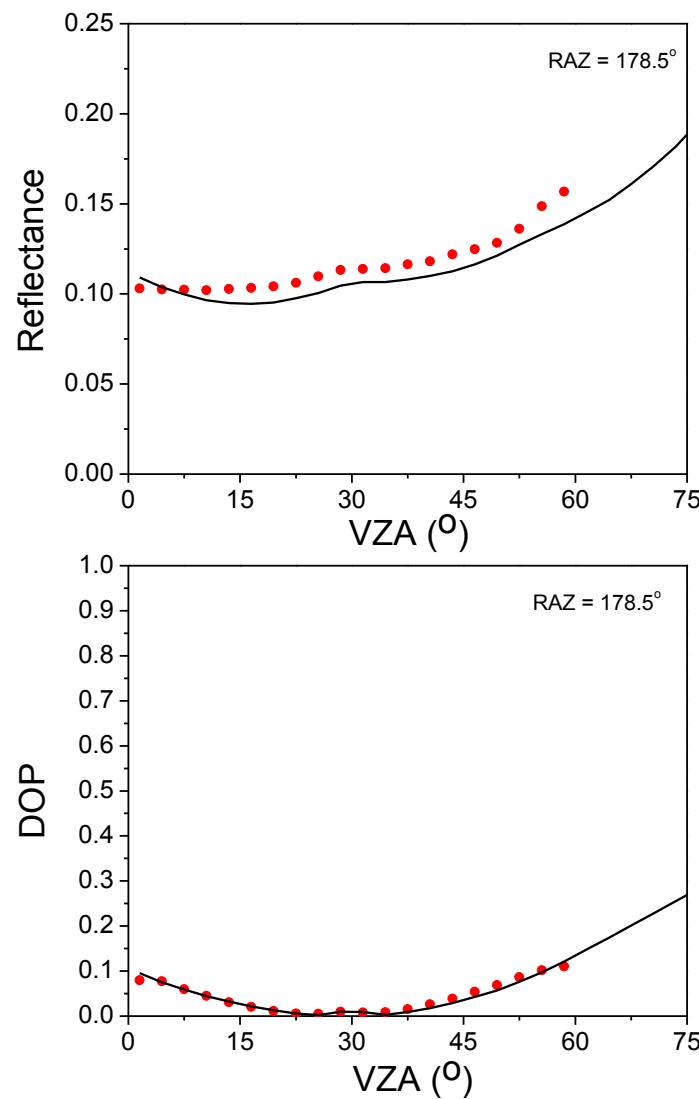
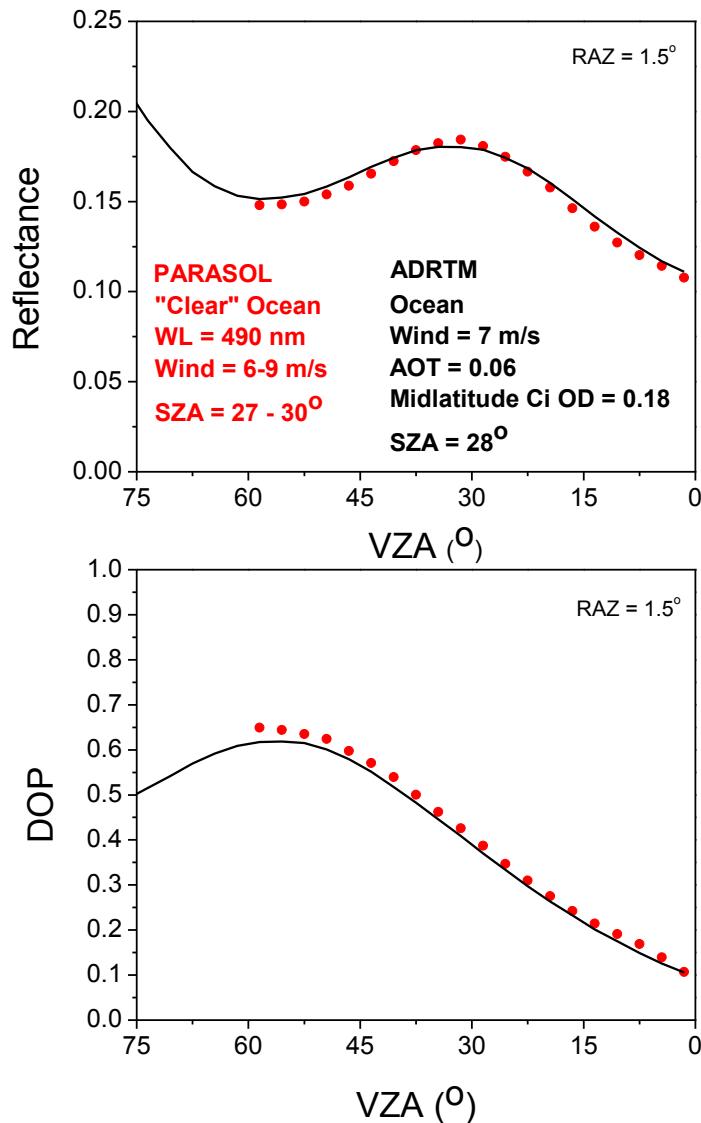
Significant difference in “clear-ocean” results, what is missed in modeling? Or what is unknown in PARASOL data?

## Undetected cirrus: A ghost in the “clear-sky” satellite data

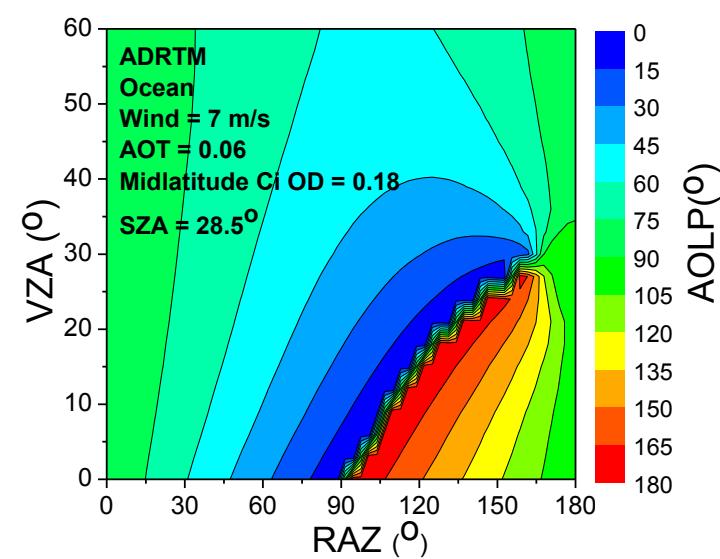
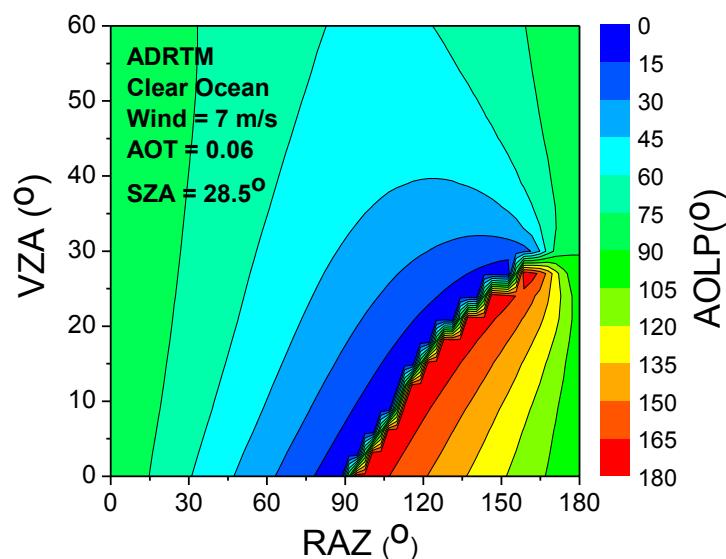
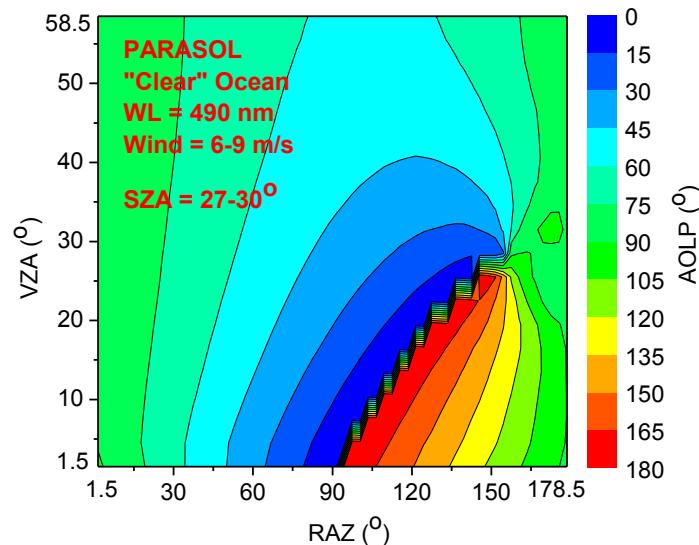


~45% of “clear sky” is actually with undetected clouds, seriously affecting temperature and AOD sensing (Sun et al. 2011a, 2011b; Omar et al. 2013).

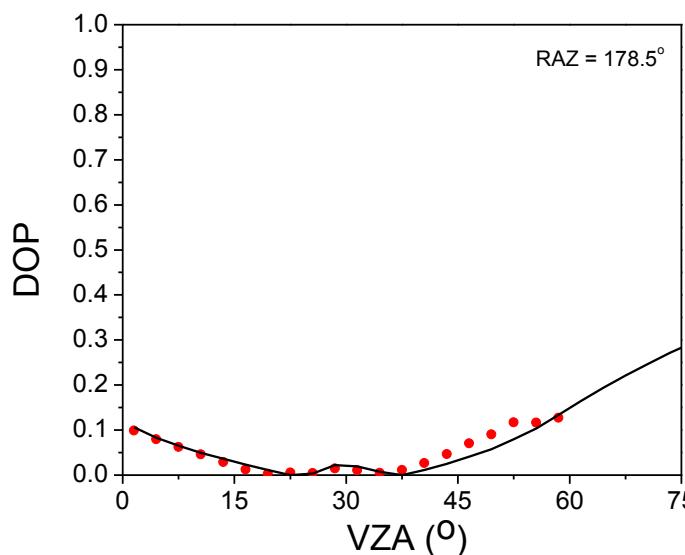
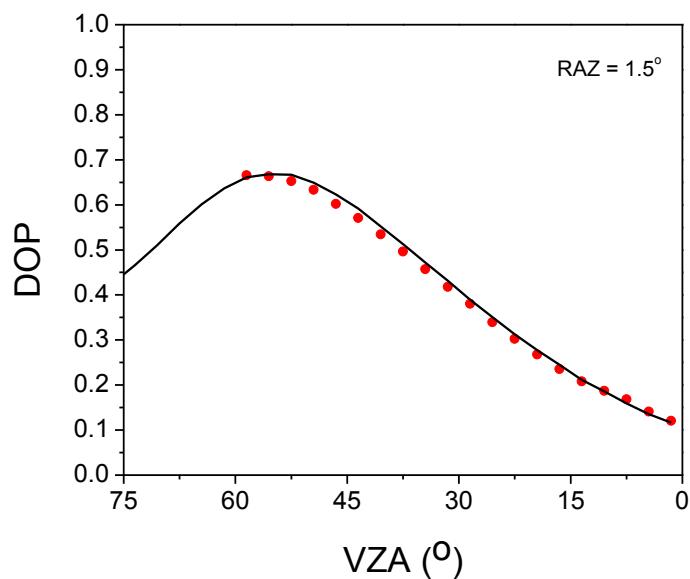
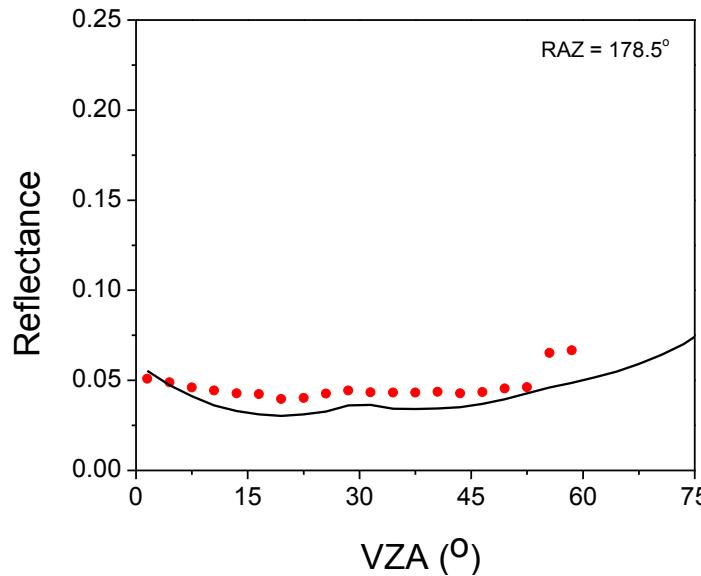
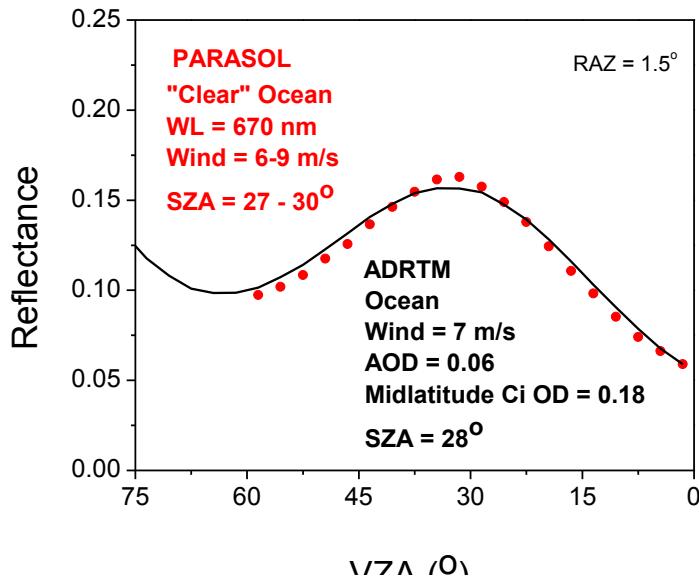
# A layer of undetected cirrus is added in the ADRTM , WL = 490 nm



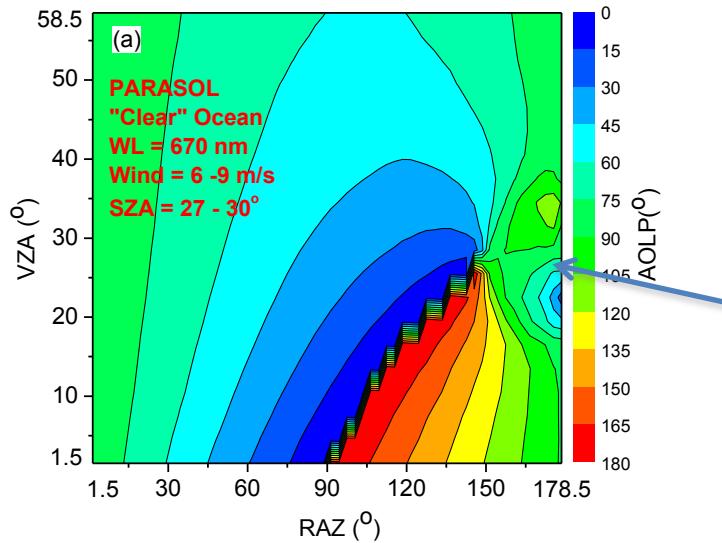
# Angle of Linear Polarization (AOLP), WL = 490 nm



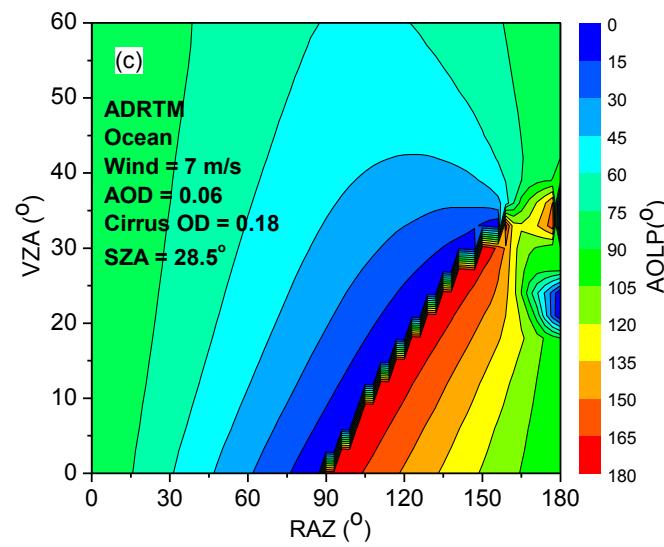
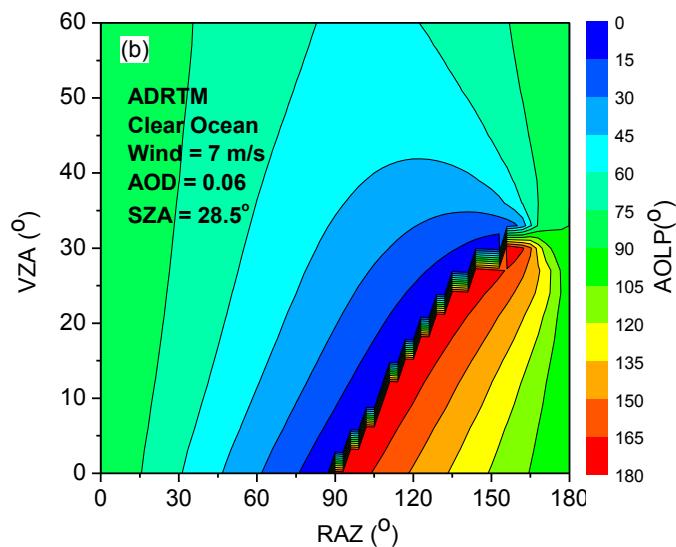
# A layer of undetected cirrus is added in the ADRTM, WL = 670 nm



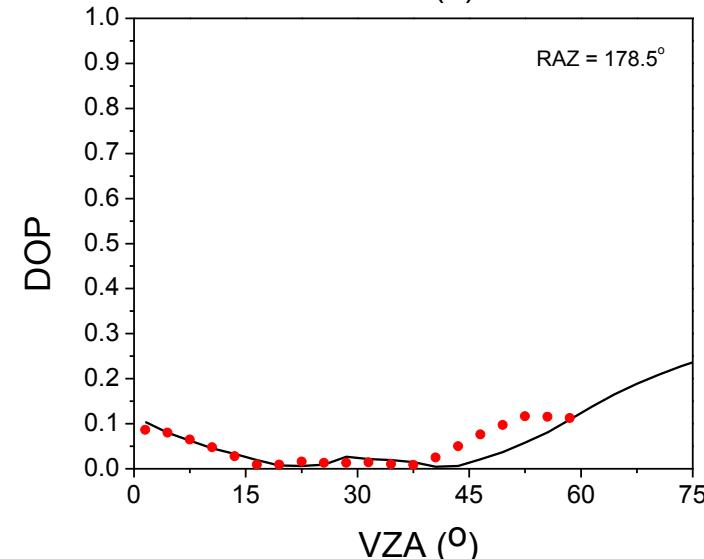
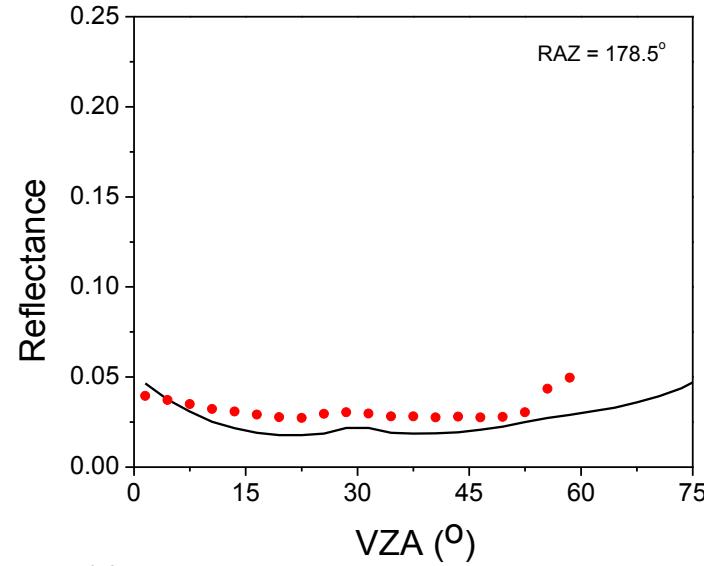
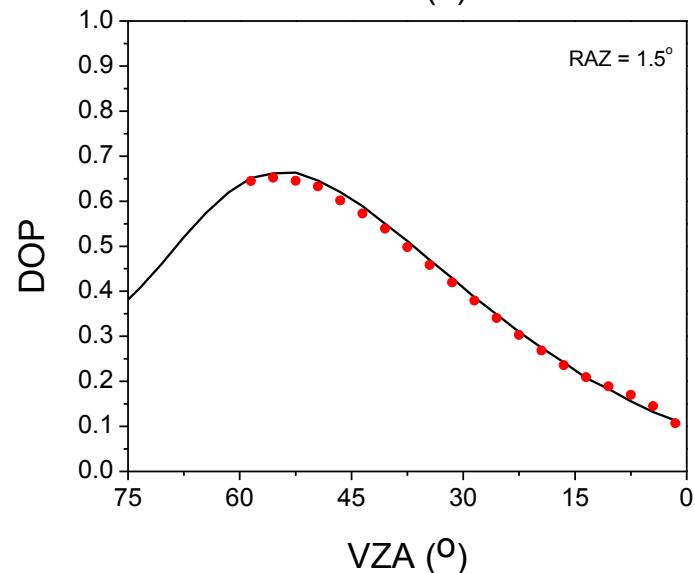
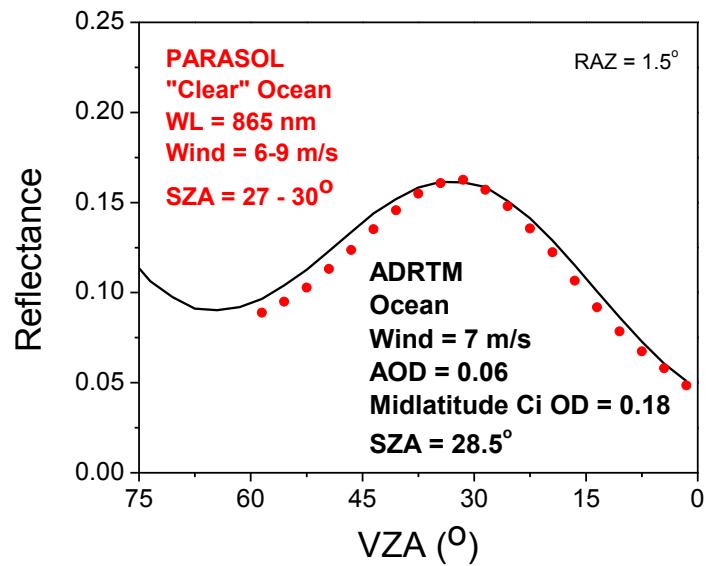
# Angle of Linear Polarization (AOLP), WL = 670 nm



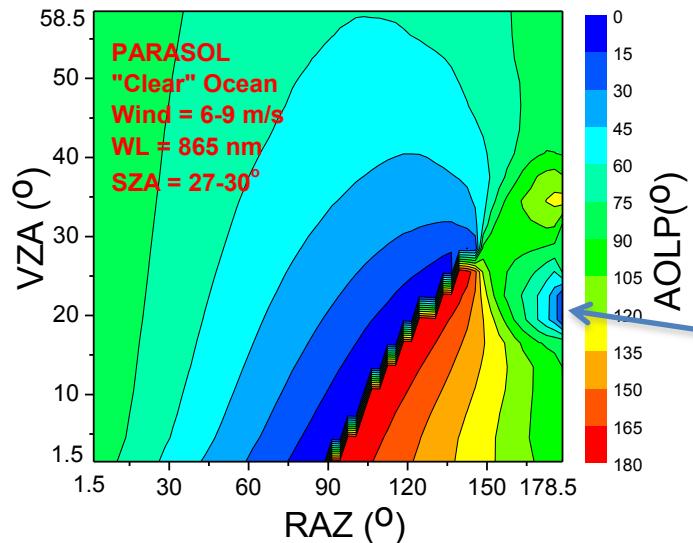
Evidence shows PARASOL "clear" footprints are contaminated by clouds.



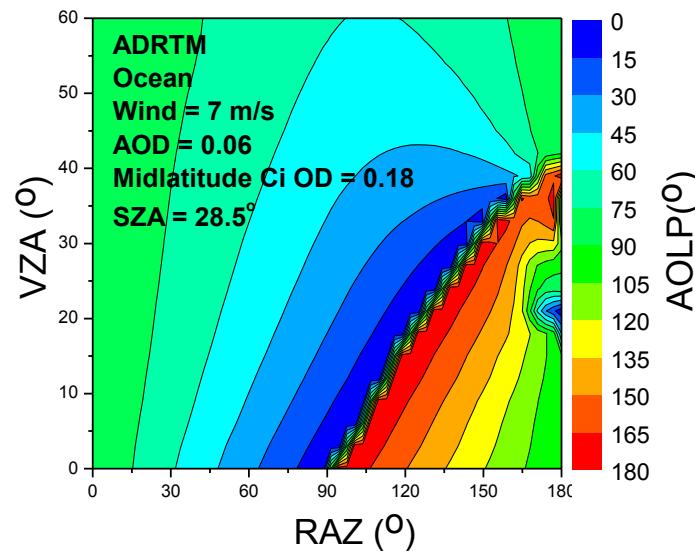
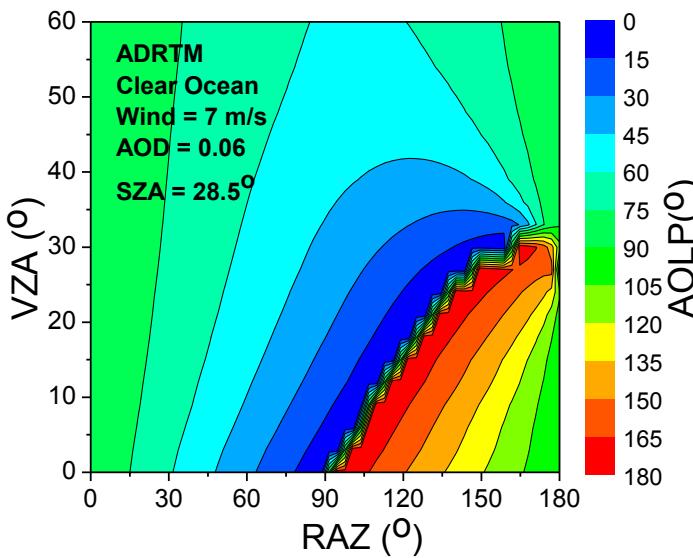
# A layer of undetected cirrus is added in the ADRTM, WL = 865 nm



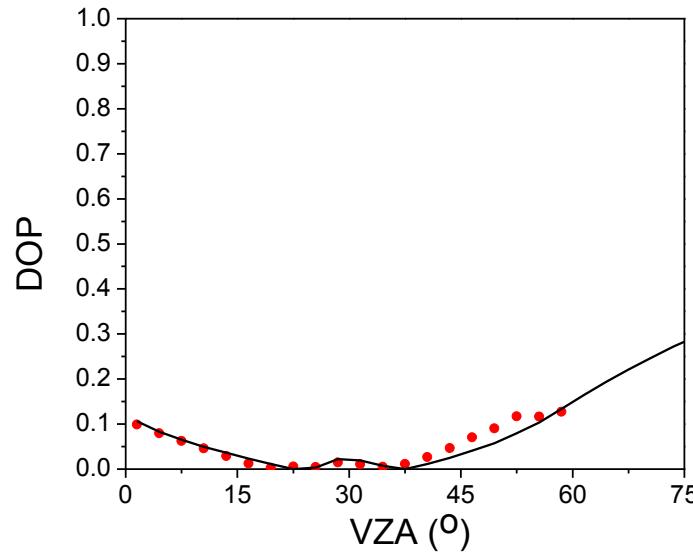
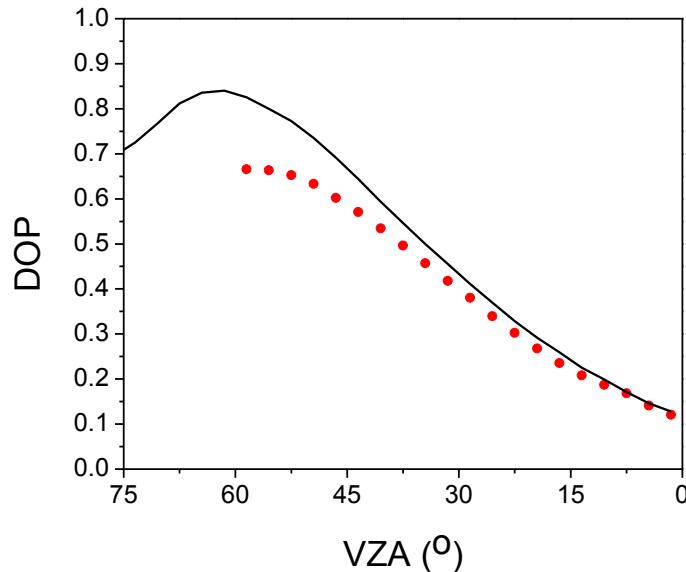
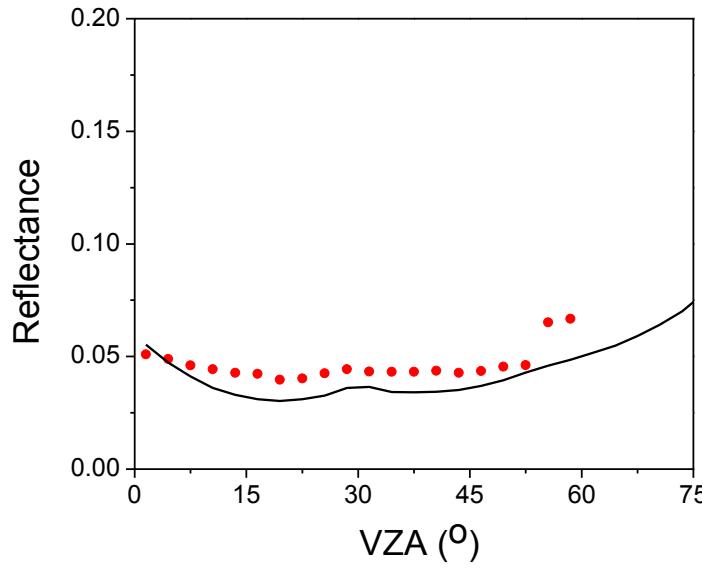
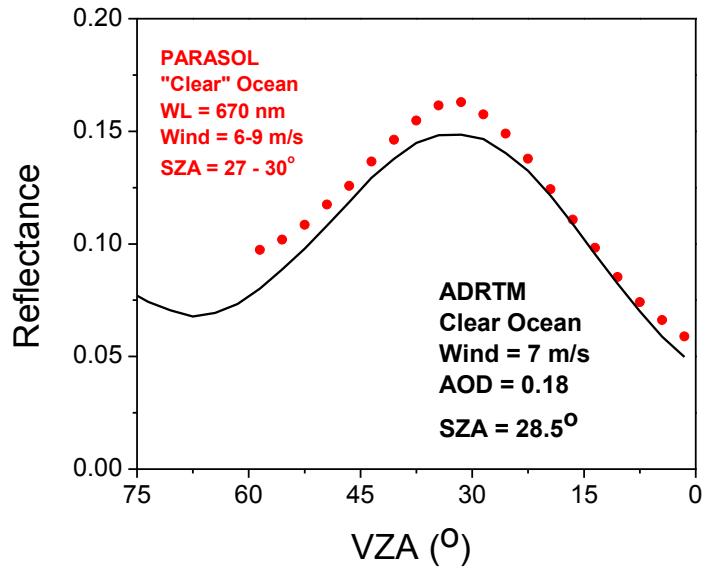
## Angle of Linear Polarization (AOLP), WL = 865 nm



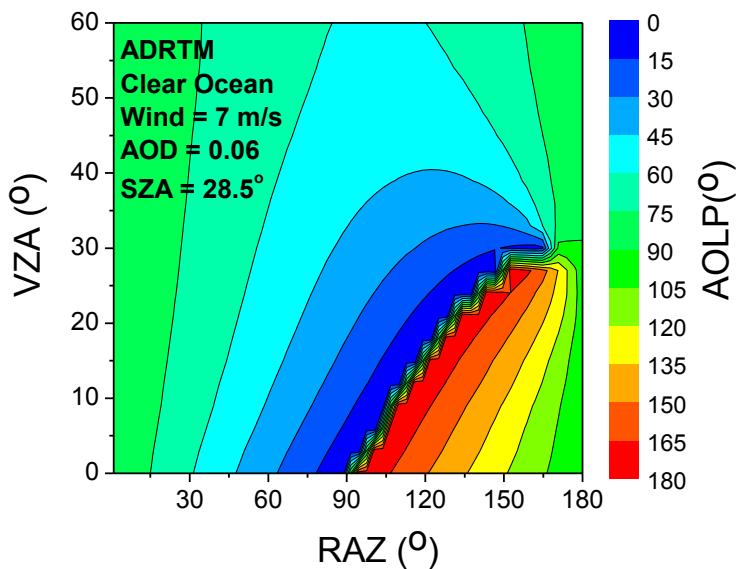
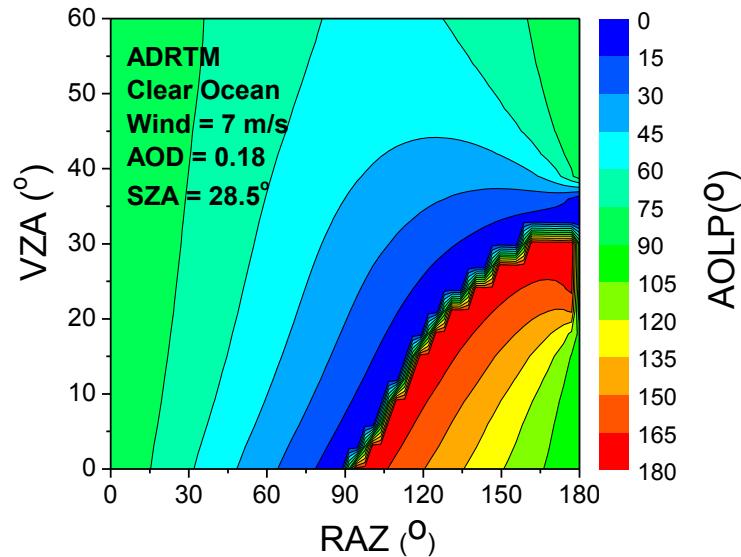
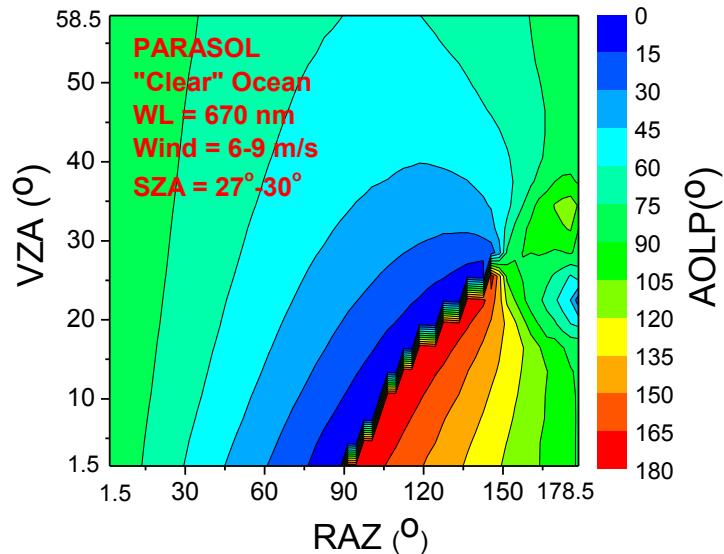
Evidence shows PARASOL  
“clear” footprints are  
contaminated by clouds.



# Does aerosol have the same effect as thin cirrus?

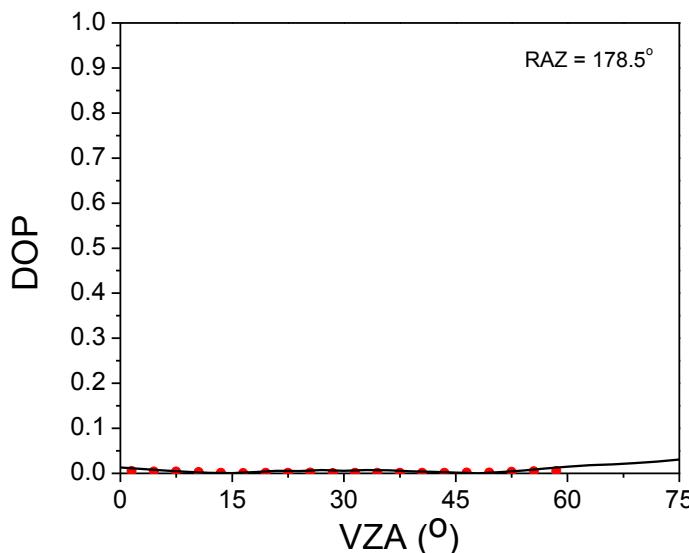
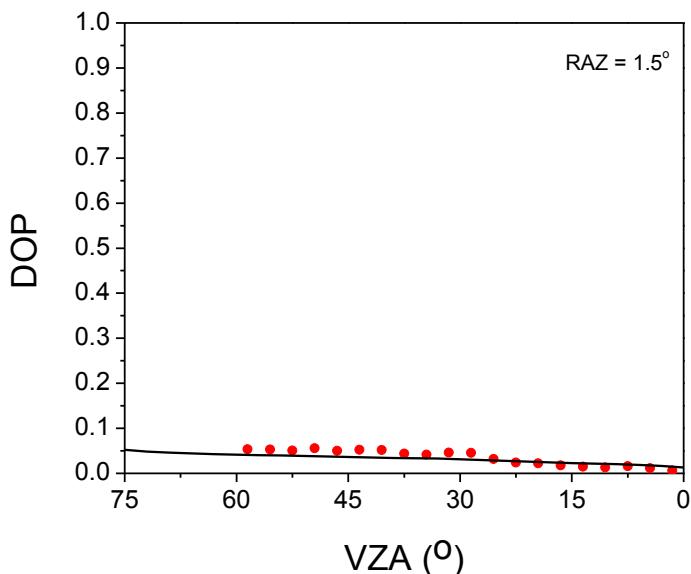
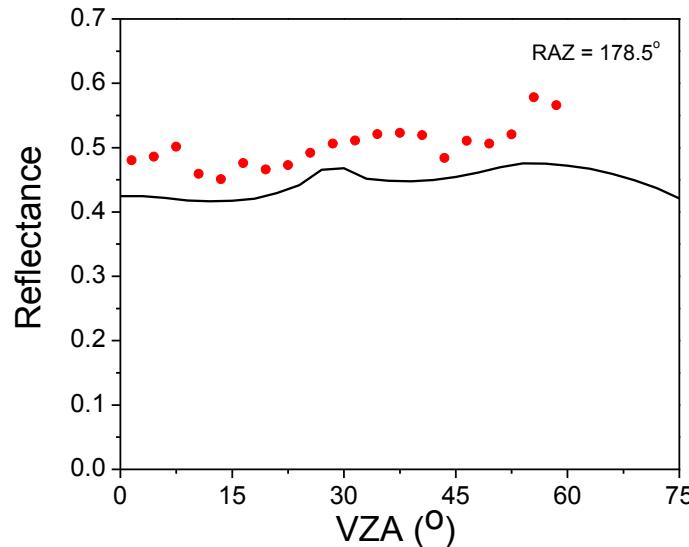
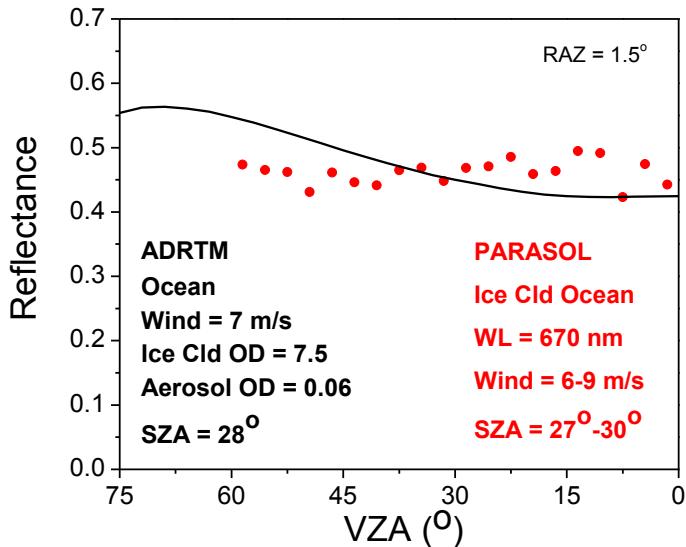


## Angle of Linear Polarization (AOLP), WL = 670 nm

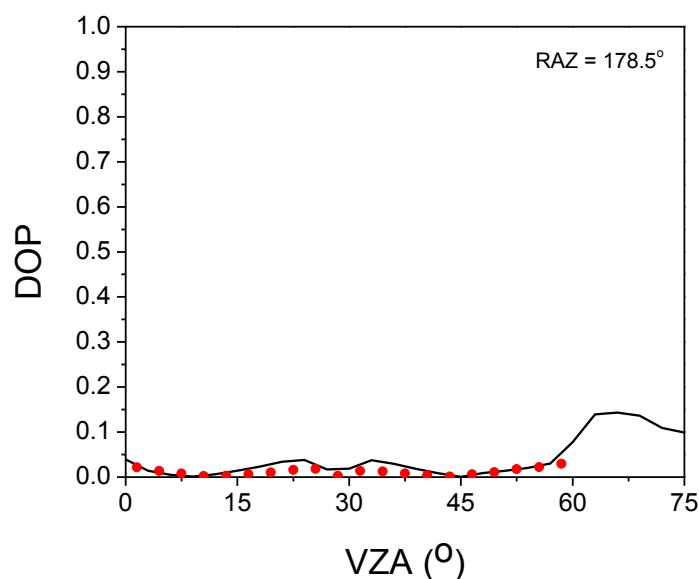
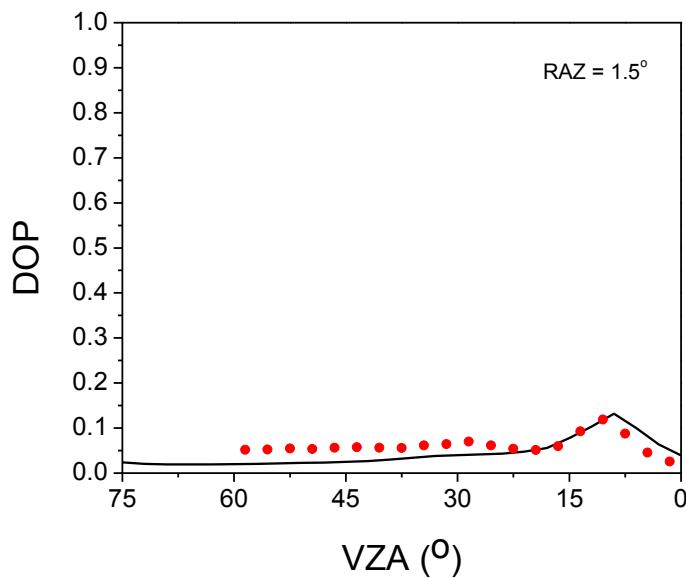
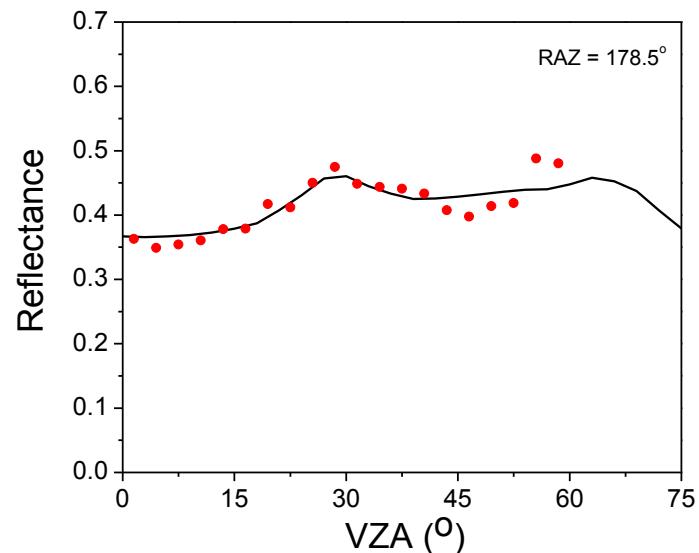
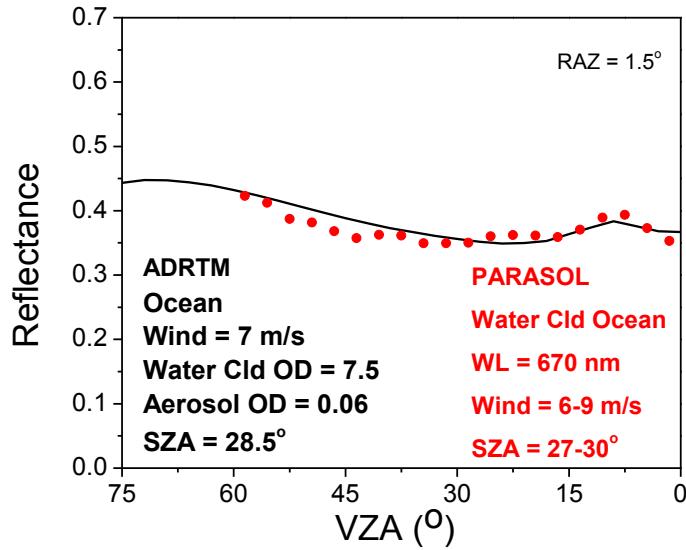


**Aerosol is not the major reason  
for the difference between  
ADRTM and PARASOL.**

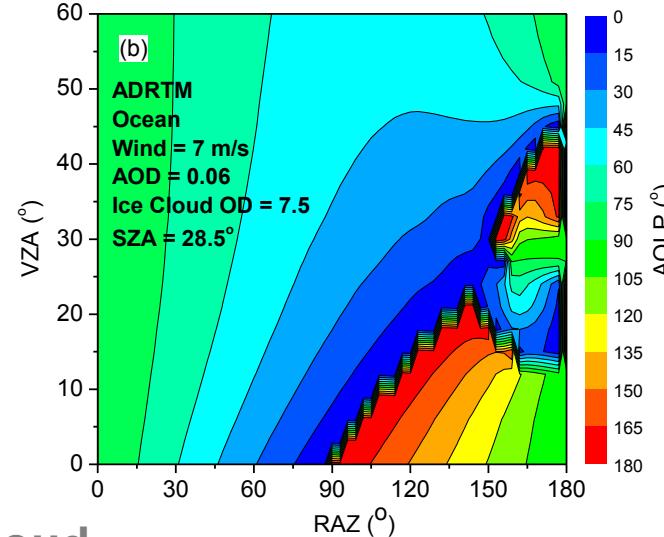
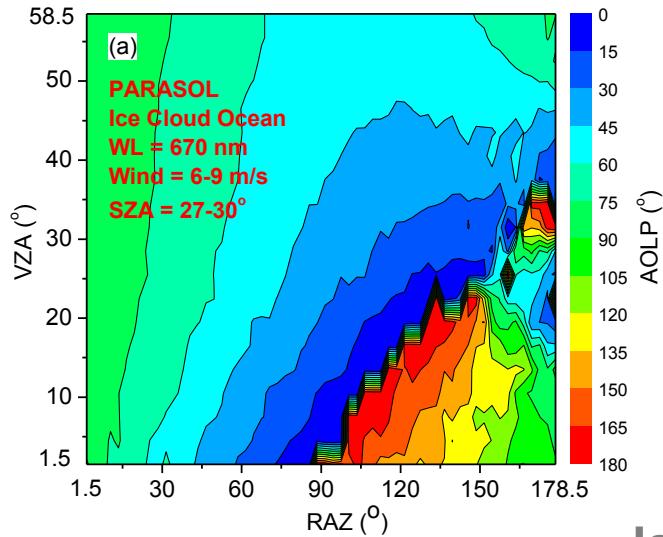
## Ice Cloud Ocean, WL = 670 nm



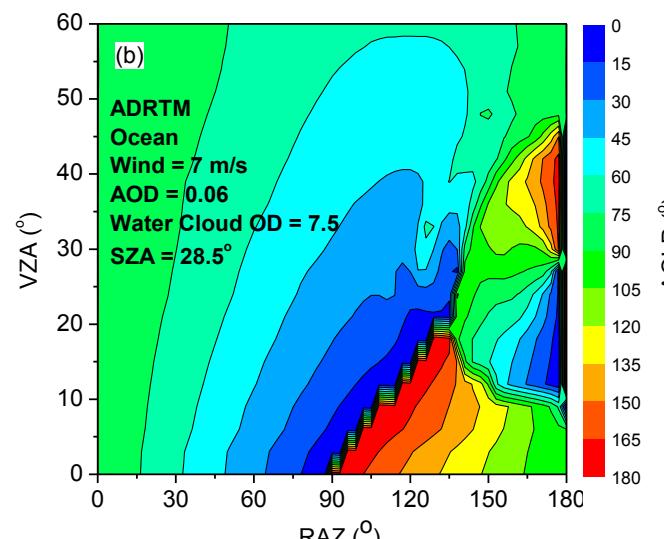
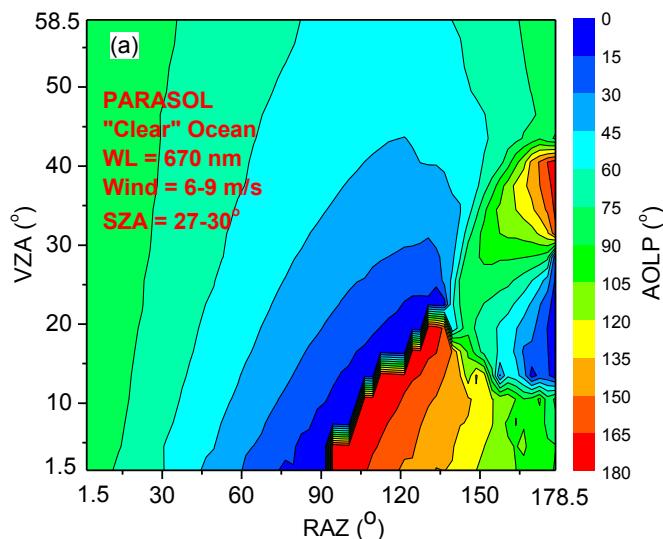
## Water Cloud Ocean, WL = 670 nm



# Angle of Linear Polarization (AOLP), WL = 670 nm



Ice Cloud



Water Cloud

## Summary

1. ADRTM results are compared with PARASOL data, demonstrating a successful modeling for polarized solar radiation.
2. The difference between model and PARASOL results is mostly due to undetected cirrus in PARASOL “clear-sky” data.
3. Undetected cirrus must be accurately accounted for, not only for PDM development, but also for many aspects of remote sensing: E.g. gas, temperature, aerosol (AERONET).

## Acknowledgment

**Detailed information can be found in following publications supported by NASA CLARREO and Glory Missions in the past 3 years:**

**Wenbo Sun**, Constantine Lukashin, Gorden Videen, and Daniel Goldin, "Modeling polarized solar radiation from ocean-atmosphere system for CLARREO inter-calibration applications: Validation with PARASOL measurements," *Atmospheric Chemistry and Physics* (To be submitted).

**Wenbo Sun**, Gorden Videen, and Michael I. Mishchenko, "Detecting super-thin clouds with polarized sunlight," *Geophys. Res. Lett.*, doi: 10.1002/2013GL058840 (2014).

**Wenbo Sun** and Constantine Lukashin, "Modeling polarized solar radiation from ocean-atmosphere system for CLARREO inter-calibration applications," *Atmos. Chem. Phys.* 13, 10303-10324, doi: 10.5194/acp-13-10303-2013 (2013).

**Wenbo Sun**, Gorden Videen, Qiang Fu, and Yongxiang Hu, "Scattered-field FDTD and PSTD algorithms with CPML absorbing boundary conditions for light scattering by aerosols," *J. Quant. Spectrosc. Radiat. Transfer* 131, 166-174 (2013).

**Wenbo Sun**, Zhaoyan Liu, Gorden Videen, Qiang Fu, Karri Muinonen, David M. Winker, Constantine Lukashin, Zhonghai Jin, Bing Lin, and Jianping Huang, "For the depolarization of linearly polarized light by smoke particles," *J. Quant. Spectrosc. Radiat. Transfer*, 122, 233-237 (2013).

**Wenbo Sun**, Gorden Videen, Seiji Kato, Bing Lin, Constantine Lukashin, and Yongxiang Hu, "A study of subvisual clouds and their radiation effect with a synergy of CERES, MODIS, CALIPSO and AIRS data," *J. Geophys. Res.*, 116, doi: 10.1029/2011JD016422 (2011).

**Wenbo Sun**, Bing Lin, Yongxiang Hu, Constantine Lukashin, Seiji Kato, and Zhaoyan Liu, "On the consistency of CERES longwave flux and AIRS temperature and humidity profiles," *J. Geophys. Res.*, 116, D17101, doi:10.1029/2011JD016153(2011).